

THE RELATIONSHIP BETWEEN THE CARBONATE AND SHOCK-PRODUCED GLASS IN ALH 84001. Charles K. Shearer and Christopher T. Adcock, Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 87131.

INTRODUCTION: One of the key controversies concerning the concept of martian bacterial life as recorded in meteorite ALH 84001 [1], is the conditions under which the fracture-filling carbonates precipitated. In that the temperature range over which hyperthermophilic microbial activity is very limited (to $\approx 150^\circ\text{C}$) [2,3], if estimates of a high temperature of precipitation are correct, the conclusions reached by McKay et al. [1] concerning martian life are invalid. One line of evidence which has been used to indicate that the carbonates formed at high shock pressures and temperatures (25 to 45 Gpa and 200°C to 500°C), is the textural relationship between the shock glass and carbonates [4]. This textural relationship has been used to suggest that these two phases crystallized from a shock induced melt [4]. The textural images presented here indicate otherwise. These images indicate that the carbonates were deposited into fractures and cavities in the orthopyroxene by two processes: precipitation at low temperatures and post-deposition fragmentation and redistribution of some of the carbonate by shock melts.

APPROACH: Two thin sections of ALH84001 (83 and 87) were selected for this textural study based on the distribution of carbonates in each sample. Textural relationships among the different phases in these two samples of ALH 84001 were studied using a JOEL 5800LV scanning electron microscope (SEM) equipped with secondary and backscattered electron and cathodoluminescence imaging detectors.

OBSERVATIONS: Carbonates deposited in fractures in martian meteorite ALH 84001 are strongly zoned in their chemical composition from calcite in their interiors through dolomite (ss) to magnesite (ss) on their exteriors (Figure 1). This zoning in the carbonates clearly formed during their growth as attested to by outlines of primary crystal faces preserved in some zones (Figures 1 and 2). Figure 1 also demonstrates that some of the extensive zoning observed in the carbonate globules is reproduced in small cavities as a result of closed system extension of the carbonate growth. The backscattered electron images presented in Figures 1-5 illustrate the sequence of carbonate globule degradation resulting from the injection or remobilization of the shock-produced glass. In these images Opx = orthopyroxene, C = carbonate, S = glass, and O = olivine. In Figure 1, the carbonate globules are attached to the orthopyroxene host and appears to have grown outward into the fracture. The textural differences between carbonates on opposite sides of the fracture give a top-bottom sense to the fracture. On the right side of the fracture, fine-grain carbonate is dispersed within the crushed orthopyroxene surface of the partially healed fracture. The carbonate globules grew on this healed surface into the open fracture. On the opposite side of the fracture, the carbonate globules are attached to an ungranulated surface of the orthopyroxene host. The initial precipitation of carbonate within the granulated orthopyroxene at the base of the fracture was followed by the precipi-

tation of the carbonate globules at the base and top. The difference in style of carbonate morphology and compositional zoning may be attributed to changes in the openness of the fluid system. A single compositional zone of the carbonate appears to be in contact with the glass and implies an equilibrium relationship. However, close examination of this carbonate surface reveals that this contact is defined primarily by fractures and that the last stage of carbonate precipitation (the outer high Fe carbonate zone) is not present in all globules. Figure 2 illustrates this relationship to a greater extent. This carbonate globule has a well developed fracture developed along its outer contact with the shock glass. An even more spectacular illustration of the dynamic relationship between the carbonate and the glass are the features that show that the complete carbonate globule was essentially detached from its orthopyroxene host. In this image, the glass appears to have been injected along the base of the globule separating it from orthopyroxene and pushing it against another wall of the fracture. Small segments of the carbonate are afloat in the glass. The contact between a broken carbonate surface and the impact glass shows no clear evidence of chemical reactions. Very minor chemical variations in the shock glass were observed as small, discontinuous bands adjacent to some of the carbonate grains. The Figure 3 image illustrates that some of the carbonate globules have been "shattered" and injected with glass. As can be seen easily, various size "shards" of the carbonate globule have been separated by the glass into a shattered mosaic. The individual pieces could be reassembled to form the original globule. Figure 4 illustrates an even more disrupted globule in which "shards" of carbonate are floating in the shock glass. Based solely on shape there is fewer clues for how these individual pieces fit together. Although broken, the "shard" still possess their original chemical "stratigraphy". In the final image of the sequence (Figure 5), small shards of carbonate are trapped within a partially healed fracture with the impact glass that transported it to its final resting place. In none of these images is there any indication that the carbonate precipitated simultaneously with the silicate glass at high temperature and pressure. These images illustrate the dynamic effect of the shock injection-mobilization of the shock glass on the carbonates that formed prior to this shock event at relatively low temperatures in a hydrothermal environment.

CONCLUSIONS: The textural evidence for a high temperature and high pressure origin for carbonates is not present in ALH 84001. More likely, these carbonates precipitated by non-equilibrium crystallization at low temperatures in an open-fracture system. The spectacular zoning in the carbonates may reflect changes in the openness of the hydrothermal system. This zoning is observed in the large globules and small cavities in the orthopyroxene. The precipitation products of this low temperature hydrothermal system were then disrupted by a succeeding shock event. There is evidence for several such events recorded in ALH

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84001 [5,6]. Injection or remobilization of a shock induced silicate melt detached and shattered many of the carbonate globules. The fragments of some of these globules were sealed in small fractures in the orthopyroxene host along with the shock produced melts that transported them. There is limited evidence to suggest that the carbonate reacted to varying degrees with the shock melt. Further, although the carbonate growth surfaces may have made hospitable environments for bacterial colonies to develop and grow, our work here and elsewhere [6] lends no evidence for this conclusion.

References: [1] D.S. McKay et al., *Science* **273**, 924 (1996). [2] J.W. Deming and J.A. Baross *Geochim. Cosmochim. Acta* **57**, 3219 (1993). [3] J.D. Trent et al. *Nature* **307**, 737 (1984). [4] E.R.D. Scott et al. *Nature* **387**, 377 (1997). [5] A.H. Treiman *Meteoritics* **30**, 294, (1995). [6] C.K. Shearer et al. *Geochim. Cosmochim. Acta* **60**, 2921 (1996).

Figure 1.

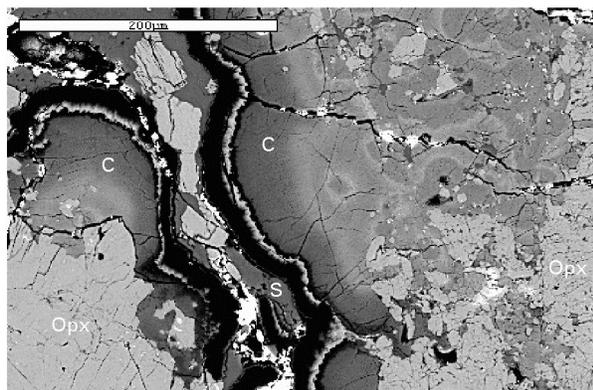


Figure 2.

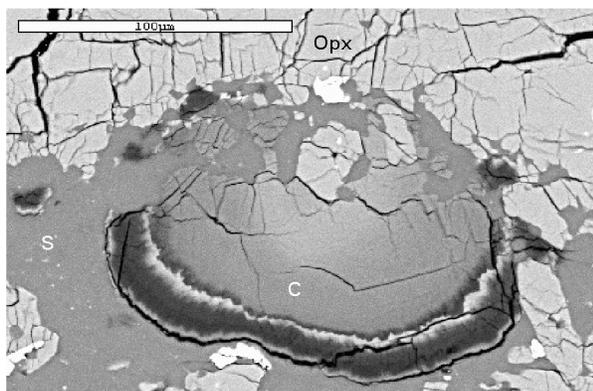


Figure 3.

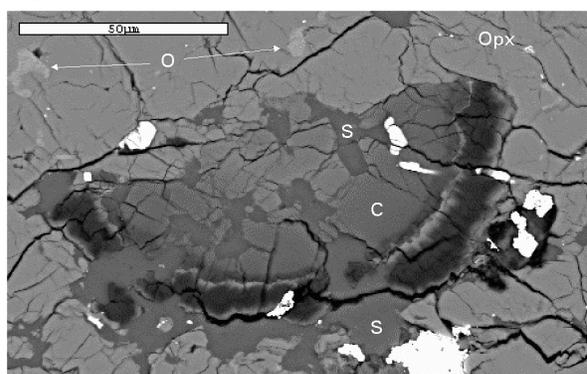


Figure 4.

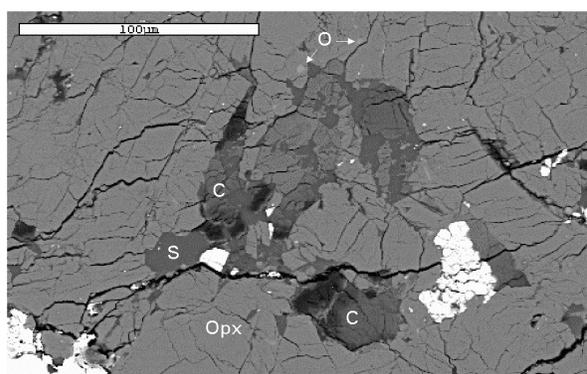


Figure 5.

